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Problems of surface air-flow and related phenomena in agriculture, horticulture and forestry

by

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AIR MINISTRY

METEOROLOGICAL RESEARCH COMMITTEE

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1. Introduction

The aim of this paper is first, to survey some eight years' experience in providing information on surface air-flow and related phenomena to workers in agriculture, horticulture and forestry, and second to set out for consideration suggestions as to future work on the problems. As may be anticipated, the particular needs of the inquirers have imposed a form and content upon the advice given, not necessarily the same as would have been adopted had the problems been viewed in purely meteorological terms. It is perhaps pertinent to emphasise that in spite of inadequate knowledge and data, we are increasingly pressed by many authorities to make some contribution towards the solution of certain problems, e.g., those which arise from the apparently conflicting claims of forestry and agriculture for extensive areas of hilly country, particularly in Scotland and Wales. The economic importance of the problem may be judged from the fact that some £25 million has been set aside under the Hill Farming (1946) and Livestock Rearing (1951) Acts, to meet 50 per cent of the cost to the farmer of a comprehensive scheme for improvement - in which the provision of shelter-belts may be included. The Forestry Commission will also grant up to £17 per acre for the planting of small areas (not less than two acres). In addition it was recommended by the Committee on Hedgerow and Farm Timber (1955) that grants should be available for approved schemes not covered by the above provision, whilst the recent Crofting Commission urged the extension of afforestation near townships - although their motive was not directly one of climatic amelioration. The value of wind-protection for horticultural crops is now being assessed (see 2a), and this promises to be substantial.

In Section 2 the various problems are set out and analysed with notes on work on hand and progress made. Section 3 deals with some of the ideas and data which have been used to clarify and partially to solve the various questions posed, and in Section 4 suggestions on future work are offered for consideration.

2. Statement and classification of problems: account of work completed or in progress

(a) Horticulture: glasshouses; farm buildings

(i) What is the distribution of wind at a given place up to the height of the building with respect to speed, direction and season: sub-classified according to temperature, precipitation and humidity, etc.?

To what extent would a wind-break of given type reduce the wind speed from some particular direction to below some stated limit? Alternatively, what type of wind-break would be required to effect a given speed reduction?

What consequential effects as a result of shading would there be on received radiation, on humidity, on dew deposition. What effect will there be on temperature especially with regard to the risk of frost?

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(ii) Given that a certain reduction in wind speed is desirable to reduce heat loss from a glasshouse at some particular time of year, what design of wind-break would be selected, bearing in mind the need not to intercept low altitude winter and spring sunshine?

What effects, if any, will such a wind-break have upon the ventilation of such a structure?

(iii) What information is there on the frequency and seasonal incidence of winds considered sufficient to cause damage to low glass structures?

In view of a given degree of danger, what measures might be taken to reduce the damage, e.g., by screening, by more secure anchorage, etc.?

The extensive literature on interrupted flow on this scale has been summarised, e.g., Gloyne (1955) and the data and concepts so assimilated as to permit an approximate answer to be given to questions posed. Complete answers are handicapped by inadequacies in the network of reporting stations of various categories in some areas of horticultural importance, e.g., as in Mid and Upper Clyde Valley, Strathmore, E. Lothian in Scotland; much of Somerset amongst other west and midland areas in England, and the potentially important areas in the west coast of the British Isles (of which many in Wales have been recently surveyed by the Agricultural Land Service of the Ministry of Agriculture, Fisheries and Food). There is also a relative lack of analysed and consolidated data on wind, and little on wind in association with other elements - the adoption of machine processing now envisaged should help materially in this respect.

Lack of knowledge of the effect of topography on air-flow handicaps progress in all fields of agricultural application, but possibly least so in horticulture.

It is not yet possible to advise confidently on the major decision as to whether additional shelter would be beneficial in any given instance. The main unsolved problems concern the best design and layout of shelter units for a particular case in the light of the cropping programme and the management policy, the economics of shelter in relation to the seasonal wind risk, the higher yield and the better and earlier produce frequently associated with the successful use of shelter. Field investigations on these topics have been carried out for three seasons jointly by the Senior Meteorological Officer at Bristol and four of the Experimental Horticultural Stations of the M.A.F.F. Provisional results for 1953-55 are now available and those for the whole series are being consolidated.

There is still much to be learnt regarding the effect of wind-breaks upon the ventilation of protected structures but this is mainly the responsibility of engineers. Extensive wind-tunnel work has brought out the main features of the problem, but the transition to full-scale phenomena with an air-flow fluctuating in speed and direction introduces new and only partially solved complications.

(b) Forestry

(i) Given a tract of country:

What are the wind hazards to forestry? What are the probabilities of an "exceptional" gale from a given direction occurring in n years?

What is the effect of topography in such gales?

(ii) How may we describe quantitatively the "climate" in those areas known to be unsuitable for trees of a given species; further how may this quantitative description be employed to identify such areas and be used in framing future policy?

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(iii) What is known of the climate in the vicinity of the forest margin?

Gales such as that of January, 1951 lend urgency to questions as posed in (i). Gale damage is reported on a minor scale every year, but major "blows" force attention to questions of policy. The forester's interest is two-fold: he wishes to assess the "calculated" risk of planting up a certain area; and secondly wishes to plan the layout of his plantation - tree species, location of roadways etc. - so as to reduce, or confine, the liability to subsequent gale damage. There are two basic requirements, first an adequate network of meteorological stations and secondly an appropriate statistical analysis of the data (not, of course, a purely meteorological responsibility). Shellard, H.C. (1956) is a valuable first step.

The quantitative description of climate - usually that of remote areas - required by (ii) suffers both from lack of data, and of appropriate methods of analysis. Some progress is being made by examining a few case histories but one of the most promising approaches appears to be on ecological lines. The general question of excessive "exposure" is certainly not a matter of wind alone - precipitation and temperature are involved and it is possible that more attention should be paid to the dry intervals between successive rains or periods of high humidity but firm criteria have yet to be devised. However advances might be hoped for as data accumulate on the rate of "tattering" (i.e., of deterioration) of flags of standard size and material now being collected at a large number of Forestry Commission Sites. So far the data collected and any appropriate wind records as are available are not inconsistent.

Question (iii) above is practically the same, meteorologically speaking, when considering air-flow in its agricultural context. A reasonably coherent picture of some aspects of the climate of the forest margin is now emerging due mainly to recent work in Germany, Switzerland and to a small degree in the U.K. The extensive work originating from U.S.A. and the U.S.S.R. is not directly relevant to conditions in the British Isles. The question of the definition, in simple geometrical terms, of the total obstruction due to a given assemblage of trees has yet to be solved, although it is being tackled.

(c) Agriculture

The problems arising in arable areas have strong affinities with those dealt with in horticulture, those in livestock areas with forestry.

(i) What climatic hazards are there to agricultural enterprises (especially to livestock farming) in a particular area?

(ii) What will be the effect of a given disposition of obstacles - natural topographical features, boulders, forest plantations of more or less irregular geometrical outline, narrow belts - in reducing the damage due to wind, either alone or in association with other meteorological elements?

The importance of shelter on any particular property will vary with the extent of the vulnerability of farm stock and farm operations to wind and weather "stress". Obviously then little can be done in meteorological terms alone in relation to a particular problem until some criteria are forthcoming from the agriculturalists: progress can however be reported.

More generally, and for application in fields other than agriculture etc., there is an acute need for more knowledge, suitably codified and presented, on the character of air-flow:

(α) over hilly, much dissected, countryside - the problem of "canalisation" arises here;

(β) over horizontal surfaces with roughness elements of various types (crops, trees, rocks, houses, hedges, etc.) disposed in various patterns;

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(γ) over terrain such as indicated in (α) with the addition of irregularly spaced trees or blocks of trees, rocks and boulders.

In its general form, the problem may well be insoluble; what might however be reasonably sought for are some empirical solutions for certain typical, but idealised, cases in those weather situations where wind is believed to constitute a limiting factor to agricultural protection. "In toto" a considerable amount of work has been done especially on (β) but the data need further reduction and analysis and more appropriate methods of presentation before results can be directly applied to agricultural needs.

(d) Phenomena involving air-borne material (including snow)

The questions come from three main groups of workers; viz., plant pathologists, entomologists and to some extent veterinary surgeons, on the dispersal and interception of spores and pollens, insects and smokes, gases and dusts from definite sources; horticultural engineers on the drift of spray particles; agriculturalists, road engineers and others on snow deposition and drifting.

Questions take the form:-

(i) What is the risk of smoke or dust deposit at a given place, due to the presence of a source at a given distance and bearing: alternatively, could a given case of damage by pollution be due to any particular source?

(ii) How far from an infected plant(s) will the concentration of disease spores fall below a stated limit: what, if anything, can be done to intercept or filter out possible disease-bearing material?

(iii) How will the natural air-flow interfere with the distribution of spray droplets or dust particles of a given size?

(iv) What information is there on wind speed and gustiness within an orchard, and how may these elements be measured?

(v) What is known relative to the interception of wind-borne material by obstacles, leaf surfaces, twigs?

(vi) What is the frequency of snow-falls in association with winds of particular strengths and directions at any given place at stated times of the year?

Recent work on turbulent diffusion and on the collection and interception of particles is sufficient to give, at any rate, a provisional answer to questions such as (i) to (iv), providing the information is expressed in an appropriate form. Inability to certify whether or not a given source was responsible for a given deposit stems mainly from insufficient information on wind distribution at the time, i.e., from data on "local" climate.

Regarding the control of snow drifts, a good deal of knowledge is well-known to both the Meteorological Office and civil engineers. The inability to utilise this knowledge for carrying out the protection of roads etc. again lies in lack of sufficient knowledge of the incidence and intensity of snow-fall and the associated wind distribution occurring in the (often remote) hilly areas where the need for economical preventative measures is most pressing.

(e) General comment

As will be apparent from the phraseology adopted in setting out the type of inquiry posed, problems under (a) and (d) are much more clearly formulated than those under (b) and (c). In respect of the former considerable progress has been made notably by civil engineers: the contribution from the Meteorological Office has varied widely from case to case, but it is not unreasonable to suppose that this contribution will gradually decrease with time.

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The situation is very different in regard to (b) and (c), and cases have arisen in which even the initial working criteria have been suggested by the meteorologist.

In broad terms the "field" of wind is required:

(i) on a regional scale;

(ii) on a medium, e.g., county, scale, down to that involving identifiable topographical units such as a range of hills;

(iii) on a local scale, e.g., the estate or farm.

It is required to identify, define and measure the role of topography; of general surface roughness due to boulders etc.; and of specific features which admit of geometrical definition - such as belts of trees and hedges.

In many cases it is not wind alone which needs to be considered (gale damage to forests is an important exception), but a complex of meteorological factors which, as far as possible, should be expressed in a few empirical relationships. From the investigational point of view the distinction mentioned above is important: air-flow can be studied with hope of success in the wind-tunnel, but the effect of a complex of obstructions on climate as a whole requires field work.

3. Notes on the sources and types of relevant information

(a) Basic climatological data. The most immediately useful tools for general advice have been:

(i) maps of mean wind speed as given in the Climatological Atlas and other material in the Meteorological Office (M.O. 3) supplemented by

(ii) results of wind surveys carried out by the Electrical Research Association, and their experiences in attempting to find suitable sites for wind-engines;

(iii) the increasing amount of data on "run-of-wind" at 2m. now coming to hand (mainly from Crop Weather Stations).

(b) Ecological data. An independent source of information stems from broad ecological criteria.

(i) Certain species of trees grown in windy spots exhibit distortion or "flagging", the crown being cut back to windward, but extended down-wind.

(ii) Low vegetation such as heather will assume a similar profile whilst the gradual decrease in the height and girth of trees, bushes, enclosed pastures and houses with increase of elevation and nearness to the sea is also broadly associated with increasing "exposure" - but probably not to wind alone. Botanically, the phenomena are considered as the variation in the position of the "moorland edge".

(iii) In recent years a third approach has been explored by the Forestry Commission, viz., "the tattering of flags" mentioned earlier under 2(b).

(iv) Evidence of "exposure" is also implicit in many farming practices, in the layout of buildings, the size and disposition of fields and hedges. Obviously such evidence must be treated with the greatest reserve, but there can be no doubt that, e.g., the very small fields in the Scilly Islands, and the high hedges of Devonshire are a consequence of coming to terms with the climate.

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(v) Semi-quantitative work has been done in Japan whereby the air-flow in selected hilly areas has been plotted by reference to the asymmetry of plant growth. The prevailing wind at different seasons could be plotted by examining the shape of different plants which were wind-sensitive at different seasons of the year.

A distinction which is of importance is between the prevailing wind and that which has been termed the "dominant" wind. On the north-east coast of England for example we find trees "flagging" towards the west: presumably therefore:-

either when the trees are particularly wind-sensitive the prevailing direction is easterly;

or only the easterly winds are associated with other factors which lead to a depression in growth.

An analogous case arises with young livestock, especially sheep, for when these are most vulnerable to "wind stress" the wind is frequently from the east and associated with a low temperature.

(vi) Evidence of the canalisation of wind can be derived from these ecological observations. A study of the distribution of the extensive damage to forests in Scotland in the north-westerly gale of January 31st, 1953 provides some pointers.

(vii) Observational studies on the grazing behaviour, posture etc. of farm livestock are being made in increasing numbers. When analysed in association with parallel weather records it is anticipated that certain broad associations will become evident relating behaviour etc. and subsequent productivity to climatic "stress".

Experience suggests that whenever the mean annual wind speed is 15 m.p.h. or more at 10 metres, as given by climatological maps, phenomena mentioned in (b)(i) are evident and that when favoured by topography similar phenomena will be found in the areas experiencing a mean speed of 10-15 m.p.h.: indeed cases are coming to hand of obvious "wind stress" inland where the general speed is less than 10 m.p.h.

The "run-of-wind" data at 2m. now available from Experimental Establishments of the M.A.F.F. are in general confirming earlier judgments of the wind hazard arrived at before the instruments were installed: the exceptions are mainly cases where relatively high rates of flow have been recorded at sites where this was not expected from climatological maps and where sufficient ecological evidence did not exist.

(c) "Canalisation"

For guidance on the presence or not of this phenomenon attention is paid to:-

(i) ecological evidence as mentioned in 3(b);

(ii) evidence implicit in the "wind roses" when available;

(iii) some findings noted in sections 3(d) below.

It has been difficult to codify observations on "canalisation" - it apparently may not occur in situations where topography leads us to suppose otherwise and contrariwise. There is, for example, clear evidence of the deflection and concentration of flow in a shallow east-west valley at Long Ashton, near Bristol, yet there are unexpectedly few observations of strong north-westerly winds, from a station at the south-east end of the deep, well-defined valley of Loch Maree in Wester Ross. It appears that "canalisation" may be an attribute of open undulating country rather than of highly dissected country with narrow, boulder strewn, or partially forested valleys - although striking cases (as judged by gale damage to forests in 1953) have occurred in such conditions.

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(d) "Break-away" of flow

Whether or not, and if so in what circumstances, flow ceases to follow the ground contours is necessary information.

Here we have been guided mainly by:-

(i) wind-tunnel studies;

(ii) the results from small scale field experiments;

(iii) field observations - mainly arising from studies in the control of snow drifting;

(iv) information from large scale field studies carried out by the Electrical Research Association and similar bodies.

Wind-tunnel work (e.g., Irminger and Noddentved (1936), Serra, L. (1951)) supplemented by small scale tests in the open (e.g., Pugh, H.Ll. (1950)) have indicated the factors likely to be of importance. The information, linked to field work on the larger scale (e.g., Pugh, H.Ll. (1950), Seligman (1936)) and taken in conjunction with evidence of the type given by Scrase (1930, page 7), on the lack of an effect on gustiness due to a smoothly contoured ridge about 30H upwind (H = height of ridge), allows the construction of a coherent picture.

It seems that "break-away" does not occur so readily in Nature as might be gleaned from wind-tunnel tests where "similarity" is judged in terms of the Reynolds number. This finding - supported by Scorer's theoretical work (Scorer (1953)) - has been further confirmed by the tank tests carried out by the Electrical Research Association (1951). Field observations, e.g., the deposition patterns of snow in railway cuttings (Anon. (1950)) and of airborne insects (Slater (1945)) and related evidence Idrac, P. (1923)), add confirmation to a rough generalisation that in circumstances of practical importance the boundary layer does not break away from windward slopes of less than 1 in 2 nor from lee slopes less than 1 in 5.

The fact that thermal stability and the speed of the "free" wind must be taken into account in the general case is rendered a little less troublesome in practice, as we are particularly concerned with wind speeds greater than 10 m.p.h. generally associated with an adiabatic lapse rate in the lowest few hundred feet.

(e) Topographic parameters

Concepts relating to up-wind ruggedness, such as "relief intensity" and "effective distance", are frequently associated with reductions in wind speed. Both these ideas are expressible in a numerical form, although whether in a relevant form remains to be seen (Conrad (1946, p. 171), Thomas, D. (1957)).

(f) Single cross-wind barriers

A great deal is known of the effect of a barrier of simple geometrical design on a normally incident wind, but there are serious gaps in our knowledge of what happens when the wind fluctuates widely in direction and when it approaches the barrier obliquely.

Furthermore conflicting accounts are given of the effect of a barrier with considerable thickness, i.e., down-wind dimension.

(g) Multiple obstructions; macro-roughness

Although there appears no evidence that a succession of widely spaced barriers (i.e., at distances apart of 25-30H or more) exert a cumulative effect on wind speed as measured and assessed by the customary techniques,

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it is incontestable that the totality of roughness elements on a tract of country will exert a drag on the flow which will increase up to a point, as the number of roughness elements increase.

The effect of this "macro-roughness" may be expressible by empirical rules giving the relationship of the surface flow over land, sea, islands etc. and the geostrophic speed (Carruthers (1943) quoting Brooks; Shaw (1931)).

There can be no doubt that if land is progressively denuded of natural features such as trees, hedges, woods etc. there comes a point when the lack of "roughness" results in a reduction in the productivity of the area and where some sort of shelter must be re-established if the area is to be successfully rehabilitated.

In certain circumstances wind erosion of soil (a "saltation" process rather than a strictly aereal one) can commence at "blowing foci" and increase unchecked to disastrous proportions if the soil surface is left bare and uninterrupted.

It is difficult to map this "roughness" in meteorological terms, but relevant information is given by:-

(i) wind profiles over various types of terrain, including built-up areas (made in, and on the margin of, such areas);

(ii) estimates of the shearing stress or of C_D (the coefficient of resistance) of isolated obstacles, of different surfaces etc.;

(iii) the variation of wind direction with height and the approach to the geostrophic wind (Ekman spiral).

Important recent work has been carried out in Denmark by M. Jensen (1954) who attempted to express the changes in wind speed which took place when a given incident wind passed simultaneously over two nearby tracts of country - one bare of natural obstructions and the other carrying a relatively dense assemblage of trees, hedges, etc.

To date the information above has been used more as "background" material than as a precise guide, but it is hoped to try and consolidate these ideas into an appropriate form.

(h) Irregular obstructions

The effect on air-flow of a block of trees, of a copse (often found in association with topographical irregularities) cannot yet be expressed in any quantitative fashion and little in the way of advice has been possible.

As such obstructions are the rule rather than the exception in those parts of the country where the problem of shelter occurs most acutely, it is obvious that urgent attempts must be made to devise suitable parameters.

(i) The zone of influence of a shelter system

In principle the definition of zone of influence in terms of wind speed, or percentage reduction of wind speed, sub-divided if necessary into seasons and direction, would appear tractable. In practice however such a division may have limited relevance to a particular shelter problem: for in actual cases we are usually concerned with a complex of events in relation to a more or less vulnerable object. Thus we require preliminary information on the susceptibility of the object to be protected before much progress can be made; work is proceeding on this.

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4. Programme of Investigations

(N.B. Those investigations, related to the several problems, in the current Meteorological Research Programme (M.R.P. 1034A) are noted in brackets.

It is recognised that, in essence, some of the information sought already exists, although widely scattered throughout the literature. A systematic re-analysis and re-appraisal of existing data will almost certainly lead to many results sufficiently accurate for present needs, but it is equally certain that a number of important gaps in our knowledge requiring both theoretical and practical study will be revealed.)

(a) The general field of wind over the British Isles

(i) The representativeness and reliability of existing data

Study of records from, and siting of, existing P.T. anemometers to assess the significance of the data in the light of any peculiarities of the site. (Items I.3.(a); II.4.(d); M.R.P. 989.)

(ii) Adequacy of the present anemometric network

Although the fundamental network is under constant review, the need for a supplementary one, using a form of integrating anemometer, would seem to require further consideration.

(iii) Statistical investigations of the general wind-field

The current (March, 1957) programme of M.O.3 appears to cover most requirements, providing studies of directional distribution and of sequences receive sufficient attention.

(b) Topographical influences on air-flow

(i) Gross effect of mountains and hill ranges on flow

The forestry/agricultural interest in work on this current PX problem might well be covered if due attention were paid to:

(α) the expression of results in terms of the geometry of the area;

(β) the use of parameters such as the standard vector distribution of winds (e.g., see G.M. No. 85, p. 21 on the relative values of this quantity over the sea and over mountainous country);

(γ) the interpretation of wind-tunnel studies, bearing in mind that immediate needs would largely be met by good qualitative agreement between tunnel and field patterns of flow.

(ii) Effect of particular topographic features on air-flow

Study by surveys, field work and possibly models of the effect on flow of obstructions recognisable on the scale of miles or tens of miles. Emphasis initially upon the interpolation "in the horizontal" and upon "canalisation".

(α) Preliminary analysis of records from sites known to be influenced by a definable topographic feature: provisional classification of sites according to degree of obstruction to wind (as revealed by characteristics of the record).

(β) Field work at selected sites. Basic instrumental requirement: either continuous recording of wind speed and direction, or "run-of-wind" according to direction (8 points). A measure of "gustiness" may become necessary later (Items III.1.(b)(c); III.3.(b)(d)(f)(g)(h): also Gold, 1936.)

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Sites and some observational assistance may be reasonably expected from interested authorities (Forestry Commission, Nature Conservancy, Hill Farming Research Organization and Universities of Durham, Edinburgh, Wales).

(γ) Surveys of selected areas using either or both of short period runs of meteorological observations and any biological criteria which may emerge.

(δ) Study, by models, is envisaged on the lines of the apparently successful methods adopted by the German Meteorological Service centered at Geissen.

(c) Effect on air-flow of specific types of roughness elements

(i) It is required to establish the broad features of the disturbance to flow by built-up areas, woods on horizontal terrain, scrubland, orchards and parkland (Jensen (1954), Carruthers (1943, p. 289); item III.3.).

(ii) On simple two-dimensional obstructions (tree belts, fences, hedges) relevant work at the Experimental Horticultural Stations (2a) and by Department of Forestry, University of Edinburgh, is reasonably adequate providing the study includes the effect of barriers on winds oblique to them.

(d) Investigations relating to the definition, measurement and distribution in space and time of "exposure"

(N.B. In the final analysis "exposure" is intelligible only in relation to the effect of various meteorological elements and combination of elements upon some body which is responsive to those elements.) Work with a high degree of priority is proceeding (Universities of Wales, Durham, Oxford) with regard to plants and animals.

In the meantime enough is known of certain of the parameters to justify limited effort on the physical aspects.)

(i) Specification of the geometry of an area with respect to "exposure"

In progress at the University of Wales. Topic is related to one being considered by W.M.O. Working Party (W.M.O. No. 48, Rc. 10. 2.2.2.2. on "Station Network").

(ii) Development of field techniques for assessing "exposure" as variously defined.

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